Introduction to Conductance Measurements For Left Ventricular Studies

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The Need for Pressure Volume Studies

Pressure and volume are two parameters that define the efficiency of any pump, be it mechanical or biological, as in the case of a living heart. The two parameters can be plotted against each other to create what is known as a "Pressure Volume" loop. This loop will represent the pump cycle from fluid input to output stage. In the case of a beating heart it can be used to assess many cardiac parameters and how well they are functioning. **Fig 1** shows a Pressure Volume loop with some of the stroke parameters indicated. The data for generating the graphs is acquired using what is known as a "Pressure Volume Catheter". Since pressure measurements are well understood by most researchers, the subject of this paper will deal mostly with the gathering of the conductance or volume data used to generate Pressure Volume loops. This paper is not meant to be a thesis on Conductance studies, it is meant to expose a cardiac researcher to the basic concepts involved in doing Pressure Volume research.

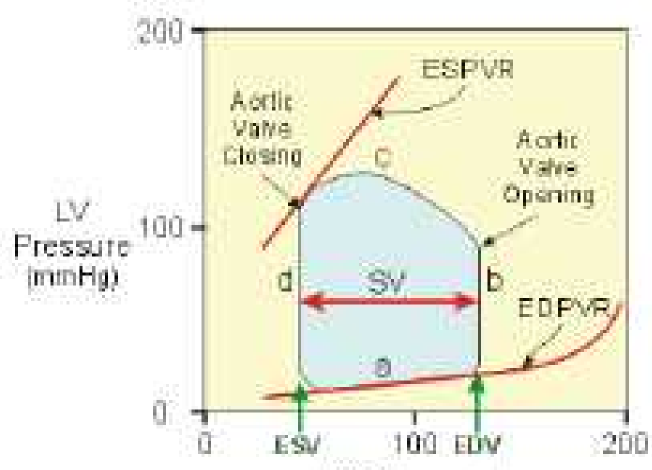

Fig 1 Pressure Volume loop showing some of the parameters that can be observed.

Basics Principles of Cardiac Conductance Studies

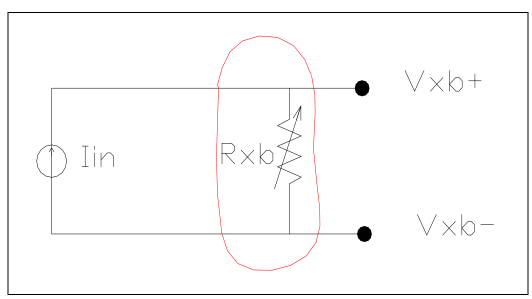

Fig 2 Showing the basic electrical model of a current passing through the blood resistance in the LV.

Left Ventricle conductance studies aim to track the changing volume of blood in the LV during a heart cycle and display the value as a voltage signal. Conductance studies are based on the most basic of electrical relationships: Voltage (**V**) equals Current (**I**) multiplied by Resistance (**R**). Referring to **Fig 2**, an AC current is passed through the length of the LV long axis. Since blood has a resistive nature, the blood in the LV is modeled as a resistor spanning the length of the long axis. Since the volume of blood in the LV changes during each heartbeat, we represent the value of the blood resistance as **variable** resistance $\mathbf{R_{xb}}$**.** The current flow through this resistor, $\mathbf{I_{in}}$ is kept constant. As the heart goes through a cycle, the changing volume of blood in the LV is measured as a **variable** voltage $\mathbf{V_{xb}}$. $\mathbf{V_{xb}}$ will be sinusoidal and have the same frequency as the heartbeat.

The tool used to inject the current and measure the resulting voltage is called a “Conductance” catheter. (**See Fig 3**) The catheter has two pairs of rings. The rings are spaced so that one set is located at the apex of the LV and the other set in located just inside the aortic valve. The closer the location of these rings corresponds to the ideal placement in the LV, the more accurate the measurements. The outermost rings (distal and proximal ends of catheter) inject the current into the blood. (I_{in}) The inner set of rings measure the voltage across the LV. (V_{xb}). The illustration in figure 3 (below) shows a pressure sensor mounted between the ring sets.

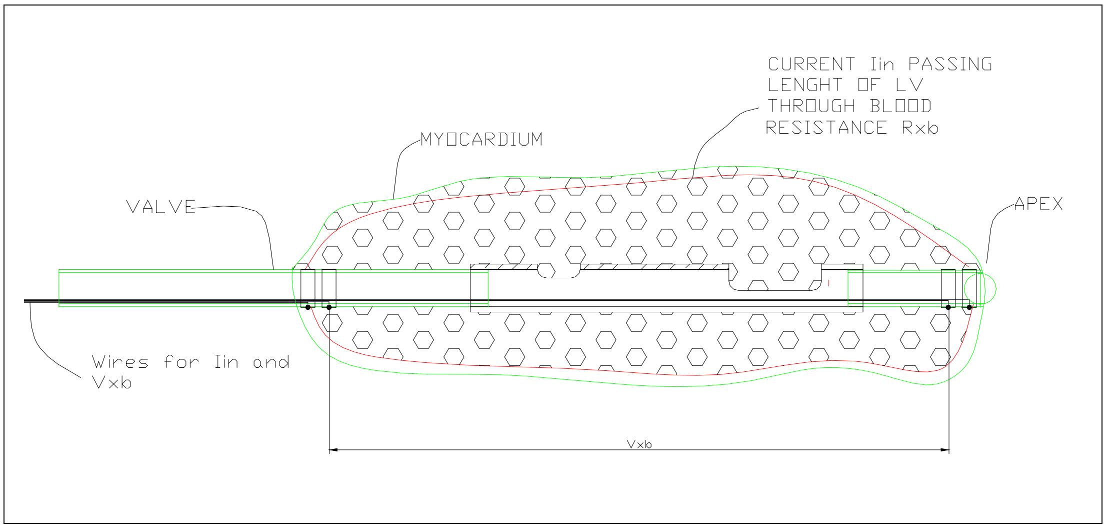

Figure 3 Conductance Catheter inserted into the LV.

Non-Idealities of Conductance Measurements

While the above explanation is accurate is somewhat oversimplified. If the study conducted needs only measure relative values of volume, the explanation and procedure will suffice. However the above explanation makes the following assumptions that are not exact:

1. The resistive value of blood is linear with volume.

2. The electrical field is contained within the LV and as such the voltage represents the volume of blood in the LV

Let's look at these 2 assumptions and see how each one will affect our results:

*Assumption # 1 - The resistive value of blood is not linear with volume. (**See Fig 4**)*
The assumption that blood volume is a linear relationship is based upon two premises: The volume of blood is modeled as a perfect cylinder with a uniformly varying diameter. The second assumption is that the electrical field generated by the current is uniform along the axis and volume of the LV. Since neither of these assumptions is true, the resulting volume to voltage relationship is compromised.

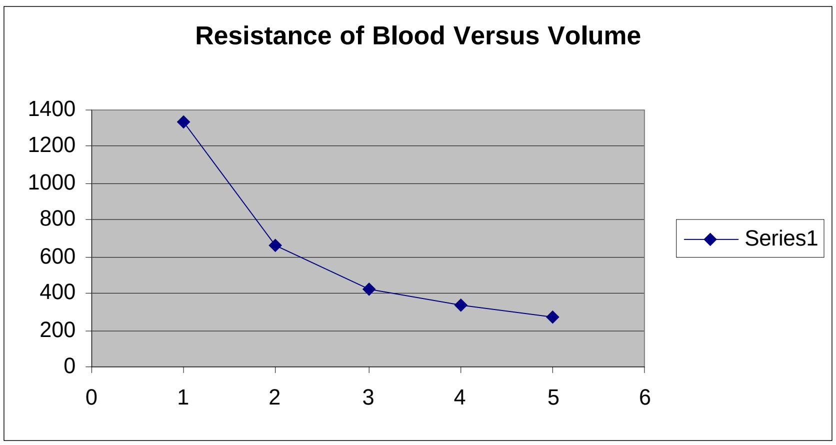

Figure 4 Resistance values (Yaxis) plotted against increasing blood volume (X axis)

To correct for the non-idealities of our assumptions, rather than using "resistance" as our parameter, we use "conductance". Conductance is the inverse of resistance (1/resistance). By plotting the conductance values of blood versus increasing blood volume, we generate a more linear relationship. (**Fig 5**) For this reason, we refer to a "Conductance Catheter" rather than a "Resistance Catheter".

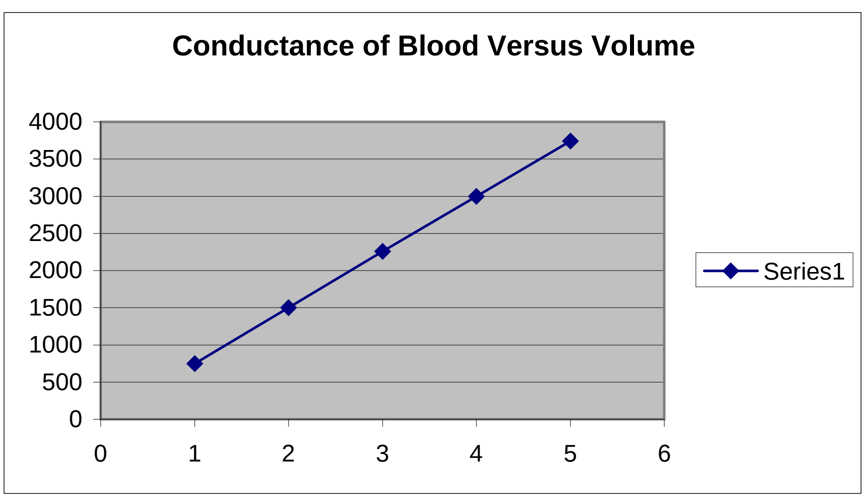

Fig 5 Conductance values (Y axis) plotted against increasing blood volume (X axis)

Assumption # 2-The electrical field is contained within the LV and as such the voltage represents the volume of blood in the LV.

This is **not** the case. The electrical field is a dipole distribution of an electrical field. As such, it will enter both blood and tissue in its path. The result is that our readings will indicate a larger volume of blood than what is actually in the LV. **Fig 6** on the next page shows the electrical model of the heart expanded to include the **parallel resistance path** created by non-blood components in the electrical field.

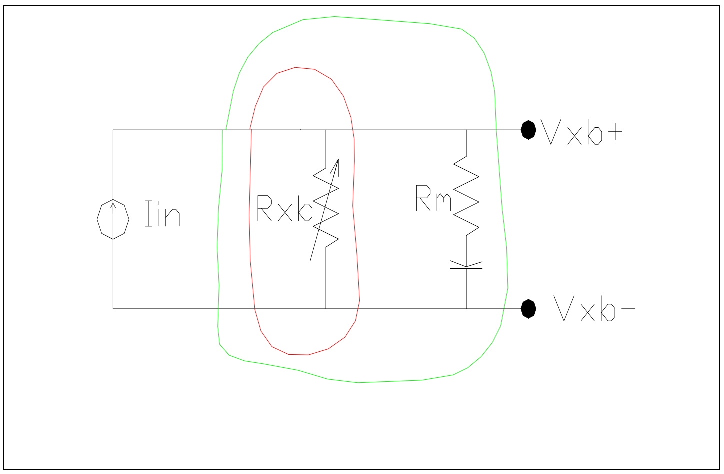

Fig 6 Expanded electrical model of the LV. R_m is the non-blood impedance seen by I_{in}

Once again, if we are content with relative volume readings, we need not concern ourselves with the addition of the parallel impedance path R_m. If however we wish to obtain values that are closer to absolute volumes of blood in the LV, we must separate the values of the two resistance paths by injecting a saline bolus.

Separating the Two Conductance Paths

To determine the relative values of our two conductance paths a bolus of hypertonic saline is injected into the blood stream, in such a manner that it does not affect the volume or pressure in the LV. Recommended doses are 10 to 20 µL of 10% hypertonic saline for mice and approximately 200 µL for rats. Typically the volume of the saline bolus should equate to stroke volume of the heart which is dependent on animal size.

Injecting this saline solution will change the resistive value of the blood. This change is then seen as an offset in the volume signal.

Since the saline will not affect the resistivity of the surrounding tissue path we can extrapolate the curve to the point where all conductance is represented by myocardial path. Commercially available software packages such as IOX from EMKA Technologies will solve a system of linear equations and correct for the parallel conductance path.

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